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Subject:	Mica Creek Study
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Attachments:	Mica_Memo_May30_2014.pdf Mica_Article.pdf

Josh –

I am just forwarding to you a document which I put down some initial thoughts on the Mica Creek Study – Why this may be of some importance to you is that OFIC referenced this study to support their conclusion that heat loading, resulting from harvest activities, does transport downstream (they might have also brought this up in your conversations). Just wanted to point out that I came to a slightly different conclusion after reading the article (which is outlined in my memo to Alan). Please do not forward this memo – Thanks. I have also attached the article.

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Influence of Timber Harvesting on Headwater Peak Stream Temperatures in a Northern Idaho Watershed

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Abstract: Concerns regarding the impacts of contemporary timber harvest practices on stream water temperature emphasize the need for improved understanding of temperature patterns and changes related to disturbances in headwater catchments. A network of water temperature recorders was installed in the Mica Creek Experimental Watershed in northern Idaho to investigate the relationships among forest treatments, stream temperatures, and riparian cover. Sensors were placed in first-order, nonfish-bearing unimpacted reaches, nonfish-bearing harvested reaches, and downstream into second- and third-order fish-bearing reaches of the stream network. Treated watersheds consisted of 50% canopy removal by contemporary clearcut methods and selective cut practices. Riparian canopy cover in the first-order reaches was measured during the pretreatment and posttreatment periods with a spherical densiometer. Despite estimated increases of up to 3.6°C in the directly impacted nonfish-bearing reaches, there was no significant increase in water temperature maxima at the downstream fish-bearing sites. Results also demonstrate that water temperatures in headwater stream networks can be highly variable and that the potential shade value of understory vegetation in harvested areas should not be overlooked. Continued monitoring at these sites is planned to evaluate peak water temperature trends during canopy regrowth and hydrologic recovery. FOR. SCI. 53(2):189–205.

Keywords: Mica Creek, water quality, canopy cover, riparian, Pacific Northwest

THE EFFECT OF TIMBER HARVEST on peak summer water temperature is a key issue for water quality, aquatic biology, and watershed management in North American forested watersheds. The debate on harvest impacts on lotic ecosystems leads to differing viewpoints for riparian canopy removal, extent and location of riparian buffers (Newton and Cole 2005), and downstream cumulative effects from timber harvesting. Effects of timber harvest on stream temperatures have been researched for over 30 years (Brown 1969, Brown and Krygier 1970). Watershed studies conducted decades ago throughout the United States found dramatic increases in stream temperature due to riparian timber harvest and site preparation activities, and increases in June–August maximum stream temperatures from 2° to 10°C were common in the Pacific Northwest (Beschta et al. 1987, Moore et al. 2005). Results from these findings were a major impetus for the passage of streamside protection regulations in most western states in the 1970s, and development of Best Management Practice (BMP) programs elsewhere (Sugden and Steiner 2003).

Summer stream temperature increases due to the removal of riparian vegetation are well documented (Harris 1977, Jackson et al. 2001), sometimes with significant stream heating cumulative effects (Beschta and Taylor 1988). Contemporary best management practices (BMP) include stream protection requirements to minimize these impacts, but more data are needed to better quantify their effectiveness. This is especially true in areas within the Continental/Maritime climate regime of eastern Washington, northern Idaho, and western Montana, where the effects of timber harvest on hydrologic processes are an important yet under-studied issue (Stednick 1996). Other studies have been initiated in British Columbia to address similar data gaps in interior, temperate watersheds (Maloney et al. 2004).

Stream heating depends on the following environmental variables: net solar (0.28–3.5 μm) and thermal (3.5–100 μm) radiation and the degree of shading by riparian vegetation, local air temperature, wind velocity, relative humidity, groundwater inflow, and amount of hyporheic flow. Groundwater can play an important role in maintaining relatively low temperatures in small streams (Adams and Sullivan 1989). Timber harvest can affect water temperature in streams in two principal ways: removal of canopy cover that increases incoming solar, but reduces incoming thermal radiation (Beschta et al. 1987), and modification of hydrologic processes that regulate the timing and quantity of streamflow (Swanston 1991). Air temperatures can provide estimations of stream temperature (Stefan and Preud'homme 1993), but local factors such as groundwater inflows can affect results (Ebersole et al. 2003, Danehy et al. 2005). Although incoming solar radiation appears to be the dominant factor at the site level (Ice 2001, Johnson 2004), modeling investigations of the cumulative effects of large-scale timber harvest emphasize that it is a complex set of factors, rather than a single factor such as shade or air temperature, that governs stream temperature dynamics (Bartholow 2000, Sridhar et al. 2004, Gaffield et al. 2005).

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Changes in water temperature regime can affect the stream aquatic biota, including fish, amphibians, and macroinvertebrates. Summer is a time of stress for juvenile salmonids rearing in streams in the Pacific Northwest; therefore, streamflows and water temperature can be factors that limit the survival of aquatic life in streams (Hicks et al. 1991). The objectives of this analysis were to (1) quantify the effects of clearcutting and partial cutting on summer peak water temperatures in headwater fish-bearing streams downstream from harvested units, and (2) measure direct harvest impacts on peak water temperature within headwater catchments.

Study Site

Site Characteristics

Similar to other research (Cafferata and Spittler 1998, Ziemer 1998), the paired watershed study at Mica Creek is one of the first comprehensive investigations in the United States of cumulative watershed impacts from contemporary timber harvest and riparian buffer management practices. The Mica Creek Experimental Watershed is a paired catchment study area in Shoshone County of northern Idaho, approximately located at 47.17°N latitude, 116.28°W longitude (Figure 1). The entire study area is a 2,700 hectare watershed that is privately held by Potlatch Corporation. The study area consists of the headwaters of the West Fork and main stem of Mica Creek, which flows northeast into the St. Joe River. The study area elevation varies from 1,000 to 1,600 meters amsl, with approximately 1,450 mm of annual precipitation. The majority of precipitation falls from November to May, with greater than 50% of annual precipitation falling as snow. The average annual air temperature is approximately 5°C, with maximum summer air temperatures reaching 30–35°C. The underlying geology is gneiss/quartzite, with V-shaped valleys and moderately sloped hillsides of 15% to 30%.

The study area comprises naturally regenerated, second-growth forest, approximately 70–80 years old, with occasional riparian stands of old-growth Western redcedar (*Thuja plicata*). Although the catchments are composed of even-aged stands of up to eight species, tree species found in the riparian zone are predominantly Western redcedar, Grand fir (*Abies grandis*), and Engelmann spruce (*Picea engelmannii*). In addition to the tree species, alder (*Alnus incanta*), red-osier dogwood (*Cornus sericea*), willows

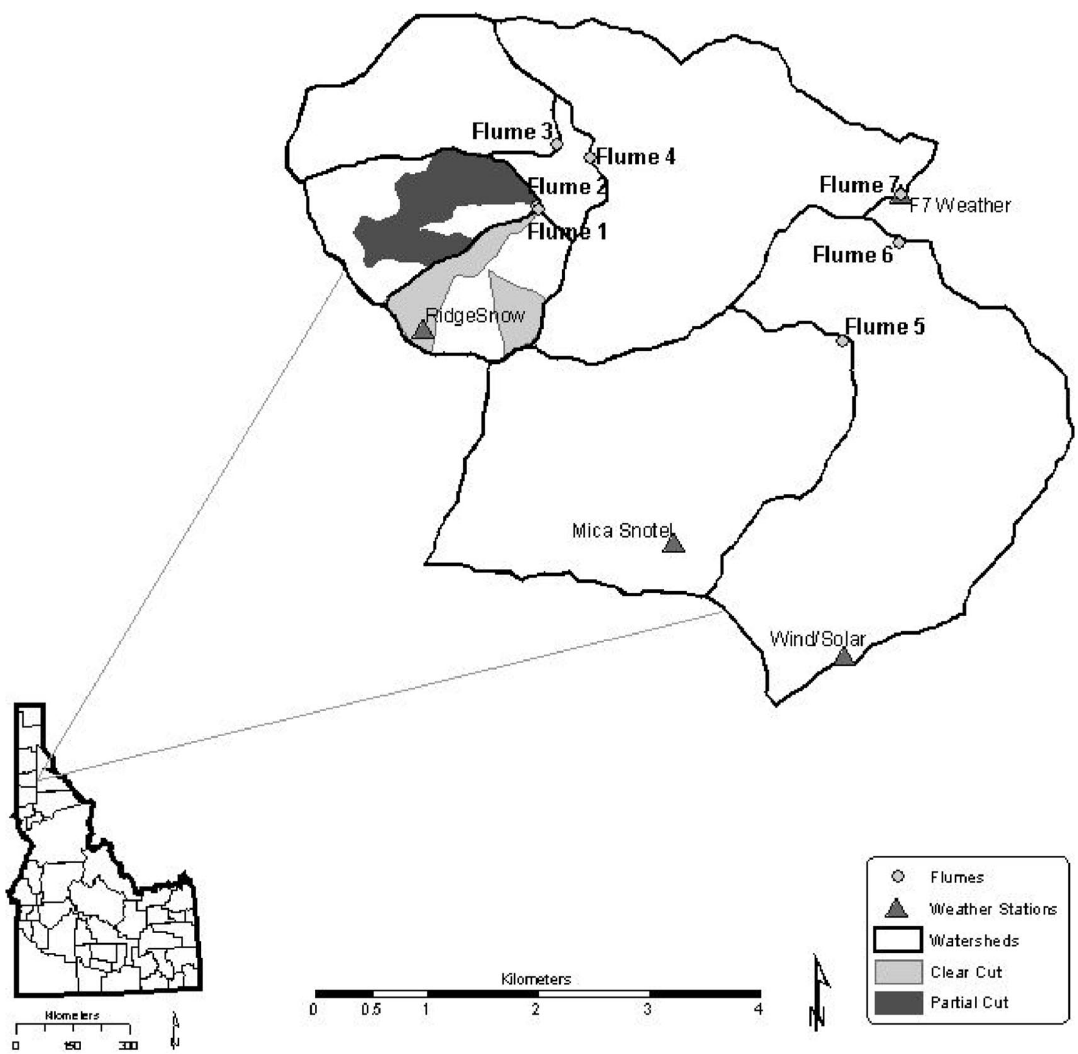


Figure 1. Mica Creek Experimental Watershed.

(*Salix* spp.), Rocky Mountain maple (*Acer glabrum*), currants (*Ribes* spp.), thimbleberry (*Rubus parviflorus*), highbush cranberry (*Viburnum edule*), and bracken ferns (*Pteridium aquilinum*) commonly compose streamside vegetation. These nonevergreen species either provide secondary stream cover as understory vegetation, or as primary shade cover in more open riparian areas.

Fish-bearing (class I) reaches in watersheds 1, 2, and 3 are relatively small headwater streams, with wetted stream widths of 1–2 m. The nonfish-bearing (class II) reaches sampled in this study were either first-order or small second-order streams, with wetted stream widths of <1 m. Stream gradients generally range from 5% to 20%. Large and small organic debris provide step-pool configurations, with riffle-run habitats in lower gradient reaches. Substrate composition varies between reaches, but the majority of substrate consists of large gravels and sands.

Site History and Experimental Treatments

The experimental area has not been harvested since the early 1930s. Parshall flumes, with Campbell Scientific CR10 dataloggers, Riverside Technology pressure transducers, ISCO 3700 portable sediment samplers, and Campbell Scientific 107 water temperature sensors were installed in the 1991 water year, and meteorological instrumentation was added subsequently. Baseline data were collected from 1991 to 1997, and roads for timber harvest were constructed in the fall of 1997. To isolate the effects of road construction from actual vegetation removal due to timber harvest, data were collected for four additional years before harvest. Harvesting took place in class II (nonfish-bearing) catchments with a combination of line and tractor skidding in 2001 and early 2002. Timber harvest and road construction activities were conducted in compliance with the Idaho Forest Practices Act Rules. Three headwater drainages on the west fork of Mica Creek (Figure 2) were used to assess and compare the impacts of harvest practices on stream temperatures (1,300–1,500 meters amsl):

- Watershed 1, where 50% of the drainage area was clearcut in 2001.
- Watershed 2, where 50% of the drainage area was partial cut (thinned), with a 50% target shade removal, in the fall of 2001.
- Watershed 3, which was designated as the unimpacted control catchment for watersheds 1 and 2.

Harvesting took place adjacent to streams also using a combination of line and tractor skidding. All Idaho Forest Practices Act regulations were followed for stream protection zone (SPZ) requirements. In Idaho these requirements are broken into two stream classifications (IDL 2000):

- *Class I streams:* Class I streams are used for domestic water supply or are important for the migration, rearing, and spawning of fish (fish-bearing). The class I SPZ must be at least 75 ft (22.9 m) wide on each side of the ordinary high-water mark (definable bank). Harvesting is still permitted, but there is restriction where 75% of existing shade must be left. There are also leave tree requirements, which is a target number of trees per 1,000 linear feet (305 m), depending on stream width.
- *Class II streams:* Class II streams are nonfish-bearing. The class II SPZ in Idaho is 30 ft (9.1 m) of equipment exclusion zone on each side of the ordinary high-water mark (definable bank). There are no shade requirements and no leave tree requirements, but skidding logs in or through streams is prohibited.

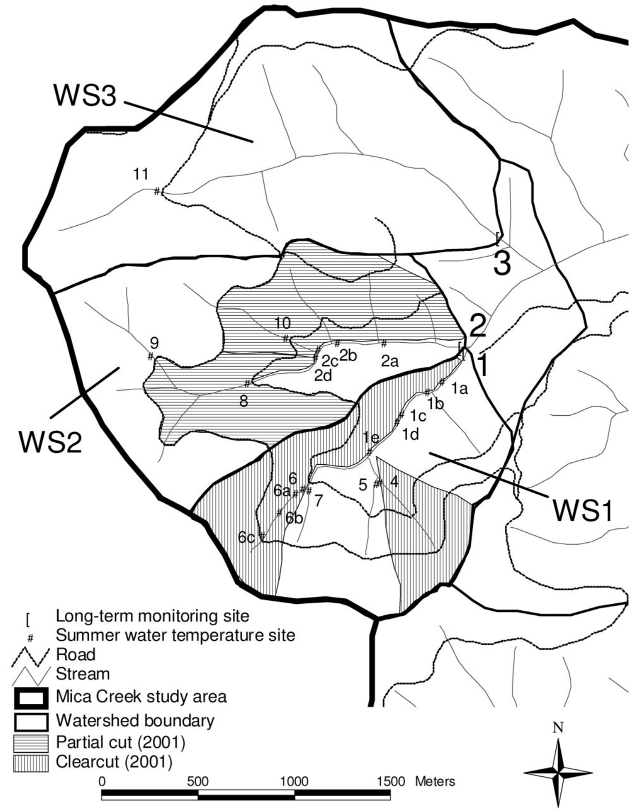


Figure 2. Mica Creek harvest units and water temperature monitoring sites.

Two-sided riparian buffers were left on all class I streams during the harvest operations. Class II streams had timber removed from both sides of the stream. After harvest, headwater catchments with clearcut treatments had only a small amount of green tree retention within the riparian zone, while in partial cut treatments equal amounts of canopy cover (approximately 50%) were removed from both sides of the stream.

Methods

Instrumentation

At all stream temperature sites, either Campbell Scientific 107 (±0.2°C) or Onset Hobo Tidbit sensors (±0.2°C) were installed. Calibration of temperature recorders were validated at low (4°C), middle (10°C), and high (20°C) temperatures in a controlled temperature water bath. Recorders that didn't meet calibration criteria of ±0.3°C were not used. In addition, automated sensor measurements were checked in situ against Hewlett-Packard digital multimeter thermometer measurements during peak water temperature periods. Sensors were replaced if differences exceeded ±0.3°C. Campbell Scientific 107 temperature sensors were used at the long-term monitoring sites. Submersible Onset Hobo Tidbit temperature recorders were placed at all remaining sites. Hobo Tidbits were placed inside open-ended 50 mm diameter white PVC tubing for protection. All sensors were approximately 10 to 25 mm above the bed surface in free-flowing water and were programmed to record instantaneous temperatures at 30-minute intervals.

Data Collection

To examine the effects of harvest treatments on summer stream temperatures, data were collected at three long-term (1992–2005) water temperature monitoring sites (points 1, 2, and 3 in Figure 2). In addition to water temperature, flow data were collected at all three sites. Within the study area, approximately 3 km southeast of harvest activity, a Snowpack Telemetry (SNOTEL) site at 1,450 m above mean sea level (amsl) was installed by the Natural Resource Conservation Service (Natural Resources Conservation Service (NRCS)) at the beginning of the experiment. Air temperature, precipitation, and snow water equivalent (SWE) were collected at this location. This station provides good baseline data for air temperature, precipitation, and snowpack (SWE) within the Mica Creek Experimental Watershed.

Additional sensors were installed following the timber harvest to assess and compare spatial stream temperature patterns in unimpacted and directly impacted stream reaches. Eight additional stream temperature/canopy cover sites (points 4 through 11 in Figure 2) were located in class II stream reaches in early summer 2001. These sites were selected according to a paired treatment/control design to measure direct harvest impacts. Sites were located in clearcut treatment reaches (4 and 6), partial cut treatment reaches (8 and 10), and undisturbed reaches (5, 7, 9, and 11). An intermediate site (point 1e) was also placed downstream of the clearcuts at the fish-presence (class I)/fish-absence interface (class II) of watershed 1 to monitor stream temperature trends and riparian buffer effectiveness between the harvest units and site 1. All sites sampled were downstream of perennial surface flow except for site 6, which was intermittent.

Pretreatment and posttreatment canopy cover was measured within the class II direct impact paired reaches (sites 4–11). To gain further understanding of longitudinal temperature trends and riparian buffer effectiveness within the fish-bearing reaches of watersheds 1 and 2, sites 1a–d and 2a–d were added in the summer of 2003. Sites 6a, 6b, and 6c were also added in 2003 to investigate longitudinal trends in the intermittent first-order reach upstream of site 6 (Figure 2).

Long-Term Site Analysis

The amount of pre and posttreatment data at the long-term monitoring sites (sites 1, 2, and 3) provides a strong before-after/control-impact (BACI) design to assess changes in peak water temperatures as a result of harvesting, and this method has been used in similar investigations (Moore et al. 2005). Data were analyzed using simple linear regression methods to estimate changes in stream temperatures following harvest, and Student's *t*-tests between the actual and predicted data values for posttreatment data.

The road construction resulted in less than 2% canopy removal, with minimal change in mid-July to mid-August water yields from 1998 to 2001 in watersheds 1 and 2 (Hubbart et al. 2007). These postroad data were therefore included in the pretreatment data set for temperature analysis. All data after July 10, 2001 were considered posttreatment for site 1 due to clearcut harvest activity. Since the partial cut harvesting occurred in watershed 2 after peak water temperatures in the fall of 2001, all 2001 temperature data at site 2 were considered preharvest. Site 3 was the control site, as no harvest activity took place in watershed 3. Maximum daily water temperatures were derived from the 30-min resolution data. Using the statistical package R (Ripley 2001, Venables and Ripley 2003), linear regression analysis was performed on the maximum daily water temperatures to compare the treated and control reaches for the pretreatment and posttreatment periods.

Temperature data were summarized as maximum daily temperatures for each calendar day of the year. It has been determined that temperatures during the summer maximum period are the most important temperature criteria for salmonid rearing and spawning (U.S. EPA 2003). Due to annual water temperature variations caused by timing and intensity of hot weather, snowpack conditions and timing of snowmelt, precipitation patterns, and streamflow conditions, temporal shifting of interannual maxima can vary as much as a month (Johnson and Jones 2000, U.S. EPA 2001, 2003). To ensure that temporal shifting in the maximum temperature period was adequately captured from the typical mid-July to mid-August summer maxima, the June 21 to September 19 period was selected as the time frame to use for all regression analyses (Figure 3). This coincides with the upper quartile of annual average maximum daily temperatures at the watershed 3 control station for the 10-year pretreatment period. Since the 7-day period of warmest daily temperatures, or maximum weekly maximum water temperature (MWMT), provides a good indicator of prolonged high temperatures and is used as a metric for both regulatory and biota assessments (WA Dept. of Ecology 2002, U.S. EPA 2003), regression analyses were also completed on the MWMT values for the two treatment-control pairs for the pre and posttreatment periods.

Direct Impact Site Analysis

Due to the lack of multiple years of preharvest data in the nonfish-bearing reaches, especially at the first-order clearcut sites, linear regression analysis using the BACI design may miss variation that a longer period of calibration record may capture. However, the limited pretreatment data (partial season at clearcut sites, one full season at partial cut sites) can provide an approximate estimate of posttreatment

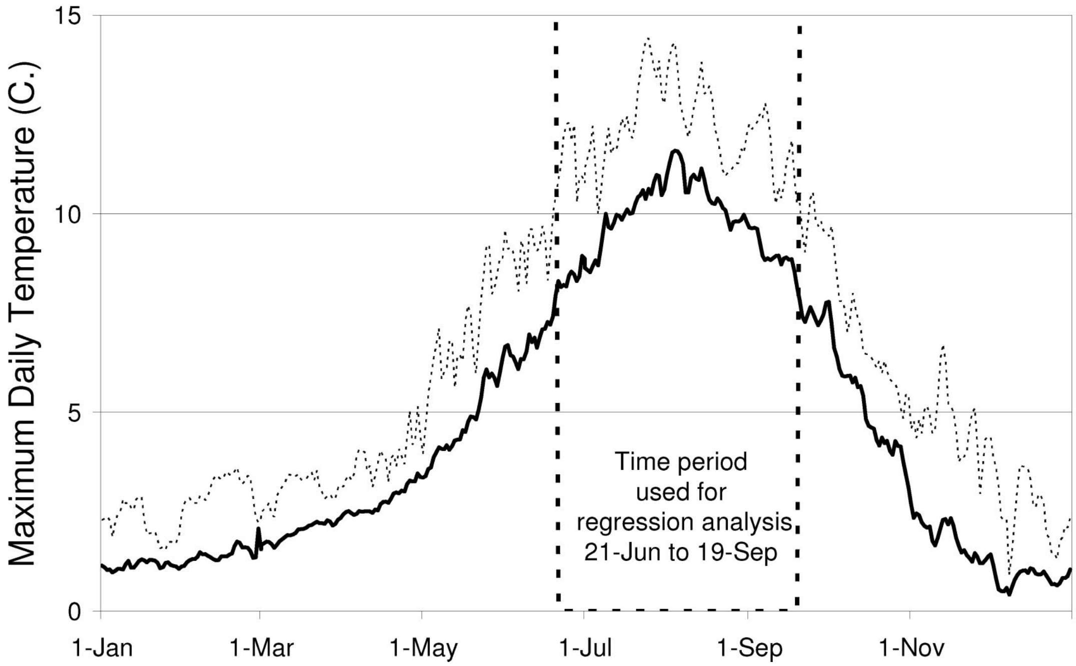


Figure 3. Site 3 (control) 1992–2001 ensemble average (solid line) and ensemble maxima (dotted line) of maximum daily stream temperature by calendar day. The time period selected for peak temperature regression analysis is indicated by the dashed lines.

effects. Furthermore, data from reaches with direct impact offer insight during hydrologic recovery as well as providing data for the development and validation of empirical and mechanistic models. To assess posttreatment peak stream temperature effects on such riparian reaches (sites 4–11, 1e), linear regression analysis was performed with the maximum daily water temperatures using the same methods used for the long-term sites. Time periods were similarly divided into pretreatment and posttreatment categories, using the same dates to divide the pre and posttreatment periods for the clearcut and partial cut catchments as noted above.

Longitudinal temperature trends were assessed by simply plotting observed maximum temperatures in the three years following timber harvest. These analyses were completed to provide an indication of the degree of spatial and temporal variability of stream temperature in the directly impacted reaches.

Canopy Cover Measurements

Pre and posttreatment canopy cover measurements at the water surface were observed in the stream reaches upstream of sites 4 to 11. Because the amount of direct below-canopy radiation is an important variable affecting stream temperature (Danehy et al. 2005), understanding the harvest effects on canopy cover and riparian shade is necessary to help analyze temperature changes.

Canopy cover measurements were made using a concave spherical densiometer (Lemmon 1956, 1957), upstream of the eight class II nonfish-bearing stream sites. Using the modified method developed by Strickler (1959), canopy cover was determined based on 17 grid intersections. Newer techniques such as hemispherical photography are widely used (Ringold et al. 2003), but densiometers were selected to provide inexpensive and rapid data collection. Despite higher measurement variability (OWEB 2000), densiometer results are highly correlated with other methods such as hemispherical photography (Kelley and Krueger 2005). Measurements were taken in two clearcut treatment reaches (4 and 6), two partial cut treatment reaches (8 and 10), and four control reaches (5, 7, 9, and 11). All canopy measurements were made in midsummer to capture similar plant phenology except in 2001, where harvest activity required these pretreatment measurements to be taken in late June 2001. Subsequent posttreatment measurements were taken annually from 2002 to 2005.

Measurements were taken 5 to 10 cm above the surface of the water. To better characterize vegetative components that provided shade to the water surface, the canopy was differentiated into two categories: total cover (defined as both overstory coniferous and herbaceous cover) and deciduous cover (defined as deciduous vegetation, grasses, and forbs). Because the majority of stream reaches had widths of only 0.2 to 0.5 m, measurements were taken facing upstream and downstream. Because of the narrow surface widths, along with vegetative trampling required to also collect left and right bank facing samples, it was determined that the two-direction sampling protocol was not only sufficient, but also the maximum amount of sampling possible to retain the structure of low-lying vegetation. At all reaches, both total canopy cover and understory cover (deciduous shrubs, forbs, and grass) were measured at 10

Table 1. Linear regression fits for long-term sites (1 and 2), WS1 direct impact clearcut sites (1e, 4, and 6), and WS2 direct impact partial cut sites (8 and 10)

Treatment site	Control site	Intercept	Coefficient	DF	Resid. Stand Error	r^2
Long-term sites						
1	3	1.706	0.804	797	0.558	0.869
2	3	0.564	0.898	891	0.532	0.898
Clearcut sites						
1e	3	−0.102	0.870	18	0.201	0.970
4	5	−2.140	1.540	18	0.554	0.883
6	7	−2.312	1.565	18	0.423	0.777
Partial cut sites						
8	11	0.871	1.043	81	0.152	0.959
10	9	1.731	0.749	81	0.115	0.983

transects spaced approximately 7.5 m apart directly upstream of the temperature recorders. Although thermal reaches are normally considered longer (Sullivan et al. 1990), it was felt that the 75-m reaches were adequate to characterize the canopy characteristics of the nonfish-bearing streams in this study because (1) the canopy characteristics within the first-order reaches were relatively homogeneous (whether in treated or control reaches), (2) wetted channel widths in the first-order reaches are generally 0.5 m or less and take less time to equilibrium than larger streams, and (3) at several sites there was less than 300 m to surface flow origination.

Results and Discussion

Results focus on the analysis of long-term temperature trends, followed by the shorter-term trends in the areas of direct impact, results of canopy cover measurements, and finally longitudinal profiles to address the complexities of headwater systems.

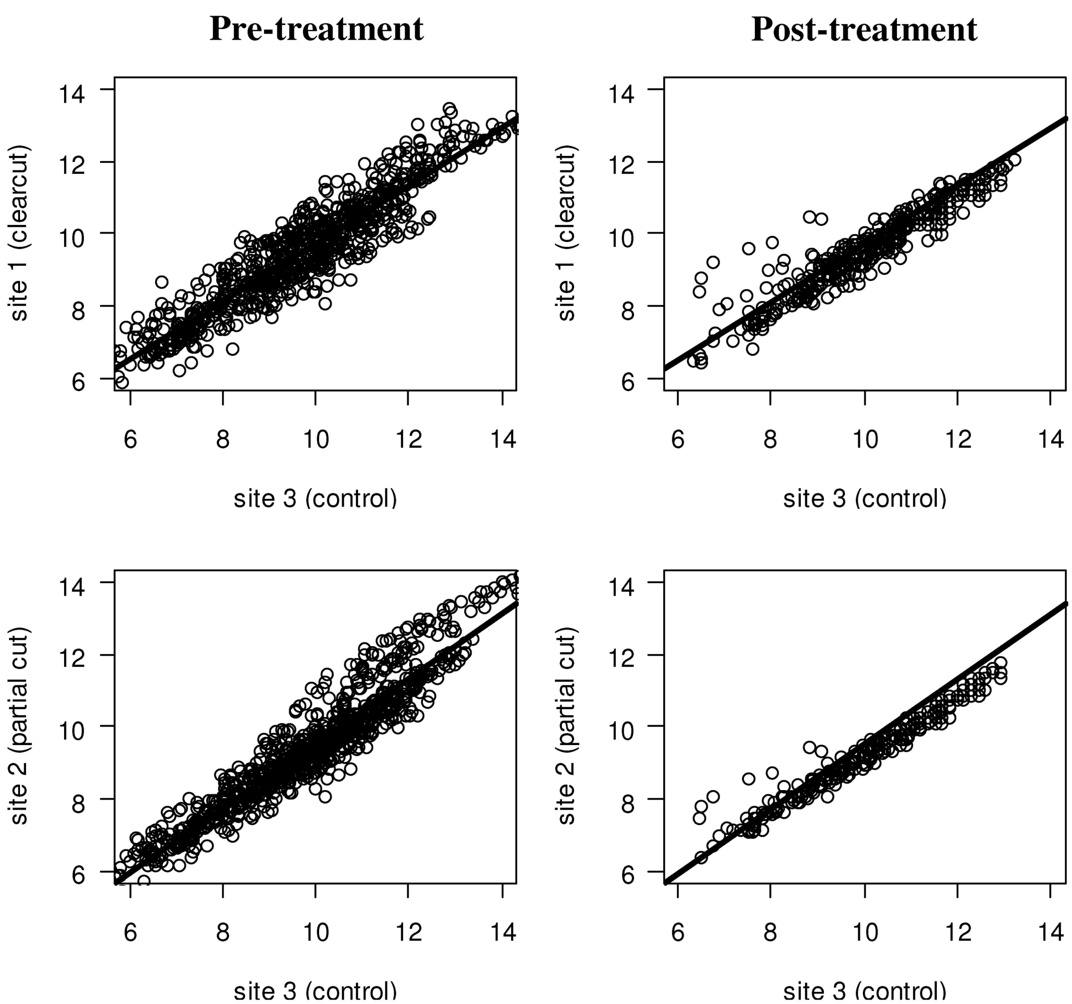


Figure 4. Pretreatment and posttreatment linear regression relationships of maximum daily water temperatures (°C) for long-term sites. Pretreatment regression lines have been added to all plots.

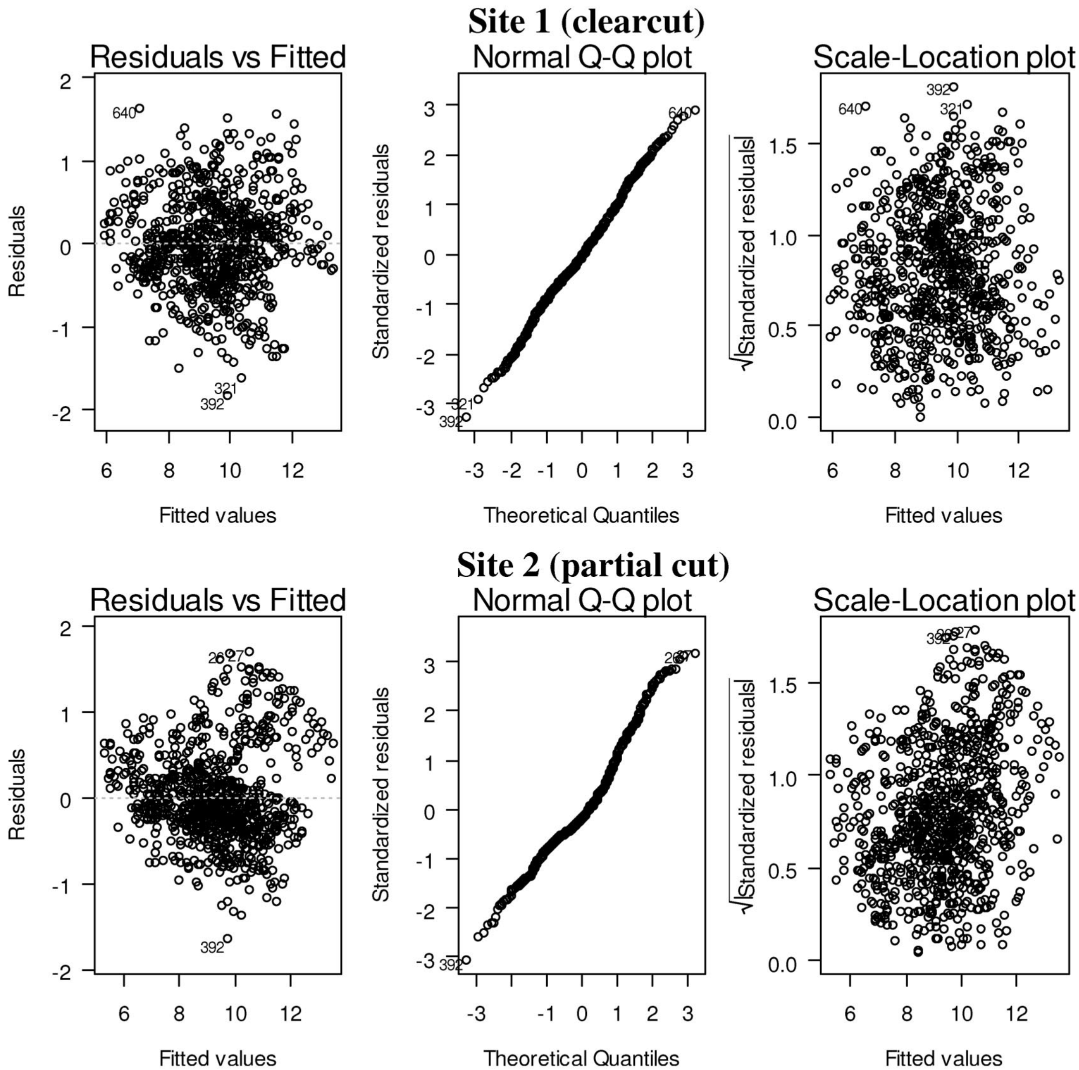


Figure 5. Site 1 (clearcut) versus site 3 (control) and site 2 (partial cut) versus site 3(control) pretreatment linear regression diagnostics.

Table 2. Student's *t*-test results for long-term sites (1 and 2), WS1 direct impact clearcut sites (1e, 4, and 6), and WS2 direct impact partial cut sites (8 and 10)

Treatment site	Predicted (°C)	Actual (°C)	*P* value	Est. change	Significant (α = 0.05)
Long-term sites					
1	9.9	9.7	<0.01	−0.2	Yes
2	9.7	9.4	<0.01	−0.3	Yes
Clearcut sites					
1e	8.8	9.2	<0.01	0.4	Yes
4	10.2	12.1	<0.01	1.9	Yes
6	7.6	7.5	0.056	−0.1	Marginally
Partial cut sites					
8	7.7	7.8	0.083	0.1	No
10	8.1	8.5	<0.01	0.4	Yes

Clearcut and Partial Cut Harvest Effects at Long-Term Sites (1 and 2)

Pretreatment and posttreatment linear regression fitting parameters for each long-term treatment/control pair are presented in Table 1, and corresponding plots are presented in Figure 4. Regression fits were relatively good, with r^2 values of 0.87 (1 versus 3) and 0.90 (2 versus 3). Fitted residual values were tested for goodness of fit and heteroskedasticity, indicating that the linear models were satisfactory to apply to posttreatment data (Figure 5). Pretreatment regressions were used to predict average maximum daily water temperatures for the posttreatment time period.

In the paired Student's *t*-tests, both the 50% clearcut and partial cut treatment sites had P values of < 0.01 (Table 2), and results showed estimated cooling effects of −0.2°C at site 1 and −0.3°C at site 2, respectively. Measured annual and predicted annual peak water temperatures were calculated from the predicted and actual values (Table 3). Results indicate a minimal cooling trend (see Figure 4). Whether the difference is due to natural variation or increases in water yield due to harvest, there is strong evidence there is no posttreatment increase in peak stream temperature at sites 1 and 2, which serve as cumulative downstream sampling points for each harvest treatment.

An examination of the maximum weekly maximum water temperatures (MWMT) and SNOTEL site maximum weekly maximum air temperature (MWMAT) does not show any marked trends in summer MWMT maxima between pretreatment and posttreatment time periods (Figure 6). Given that MWMAT from 2002 to 2005 at the SNOTEL site was at the upper range for the comparison period of record, an increase in MWMT would not have been unexpected. Figure 7 summarizes pretreatment and posttreatment MWMT relationships of 1 versus 3 and 2 versus 3.

Even though increased maximum temperatures were not detected at the long-term sites, there is the possibility that a change in the seasonal variability of the peak temperature could affect aquatic organisms that have temperature-dependent life cycles. Based on a summary of the timing of peak water temperatures (Table 4), the observed maxima offer little indication that timing between sites 1, 2, and 3 has changed due to harvest. Peak timing observations appear to be closely related to the occurrence of summer air temperature maxima (Figure 3).

Annual amounts of precipitation, the absolute amount of snowpack, the ratio of snowfall to rainfall, the timing of snowmelt, the timing and amount of summer rainfall, and the distribution of catchment residence times may all contribute to annual variability that may negate the ability to detect small changes in summer low flows. Nonetheless, during the low flow period of July through October, there was a significant increase detected of over 1 mm (5%) following clearcut harvest (Figure 8; Hubbart et al. 2007). Slight cooling also appears to be occurring at WS2, although the posttreatment increases in base flow are less apparent.

Stream temperature effects from flow increases may not be limited to low flow periods. For example, while performing regression analysis, data showed that treatment/control relationships between 1 versus 3 and 2 versus 3 in late June 2002 differed from other years. Points that diverged from the posttreatment relationships (see Figure 4) occurred at this time. This appears to be the result of high snowpack levels remaining late into the spring and early summer of 2002 as a result of above-average (120%) snowpack that occurred during the preceding winter. The control watershed (WS3) appeared to still have snowmelt runoff that limited daily maximum water temperatures in late June. This disparity could be the result of the timber harvest, where the timing of the snowmelt in WS1 and WS2 was accelerated. These greater increases in early summer stream temperatures could have an impact on sensitive stages of aquatic biota (Johnson and Jones 2000). Impacts could be either positive or negative, as warmer temperatures early in the summer could potentially increase net primary productivity. Although this same scenario may repeat itself in other years, it does not appear to affect the midsummer period of July to August. This example of temperature divergence provides justification to characterize these differences in terms of a holistic temperature regime (U.S. EPA 2001), but it is beyond the scope of this investigation of peak water temperature. Future analyses will address early season temperature impacts from timber harvest.

Clearcut and Partial Cut Harvest Effects at Direct Impact Sites (1e, 4, 6, 8, and 10)

Linear regression correlations between maximum daily water temperatures at the direct impact clearcut and adjacent forested reaches had r^2 values of 0.97 (1e versus 3), 0.88 (4 versus 5), and 0.78 (6 versus 7). Maximum daily

Table 3. Posttreatment measured versus predicted annual peak stream temperatures (°C) for long-term sites (1 and 2), WS1 direct impact clearcut sites (1e, 4, and 6), and WS2 direct impact partial cut sites (8 and 10)

	Long-term sites		Clearcut sites			Partial cut sites	
	1	2	1e	4	6	8	10
2002							
Measured (°C)	11.5	10.5	10.7	14.9	8.8	8.8	9.2
Predicted (°C)	11.2	11.2	10.2	11.3	8.0	8.2	9.0
Estimate change	0.3	−0.7	0.5	3.6	0.8	0.6	0.2
2003							
Measured (°C)	11.8	11.8	11.5	16.3	8.8	9.5	10.7
Predicted (°C)	12.1	12.2	11.1	13.4	9.5	9.7	10.7
Estimate change	−0.3	−0.4	0.4	2.9	−0.7	−0.2	0.0
2004							
Measured (°C)	11.5	11.5	11.0	14.7	7.8	9.3	10.5
Predicted (°C)	12.1	12.5	11.1	13.4	9.5	9.4	10.2
Estimate change	−0.6	−0.7	−0.1	1.3	−1.7	−0.1	0.3
2005							
Measured (°C)	11.1	10.9	10.4	13.9	7.7	9.0	10.1
Predicted (°C)	11.5	11.5	10.5	12.5	9.2	9.2	9.9
Estimate change	−0.4	−0.6	−0.1	1.4	−1.5	−0.2	0.2

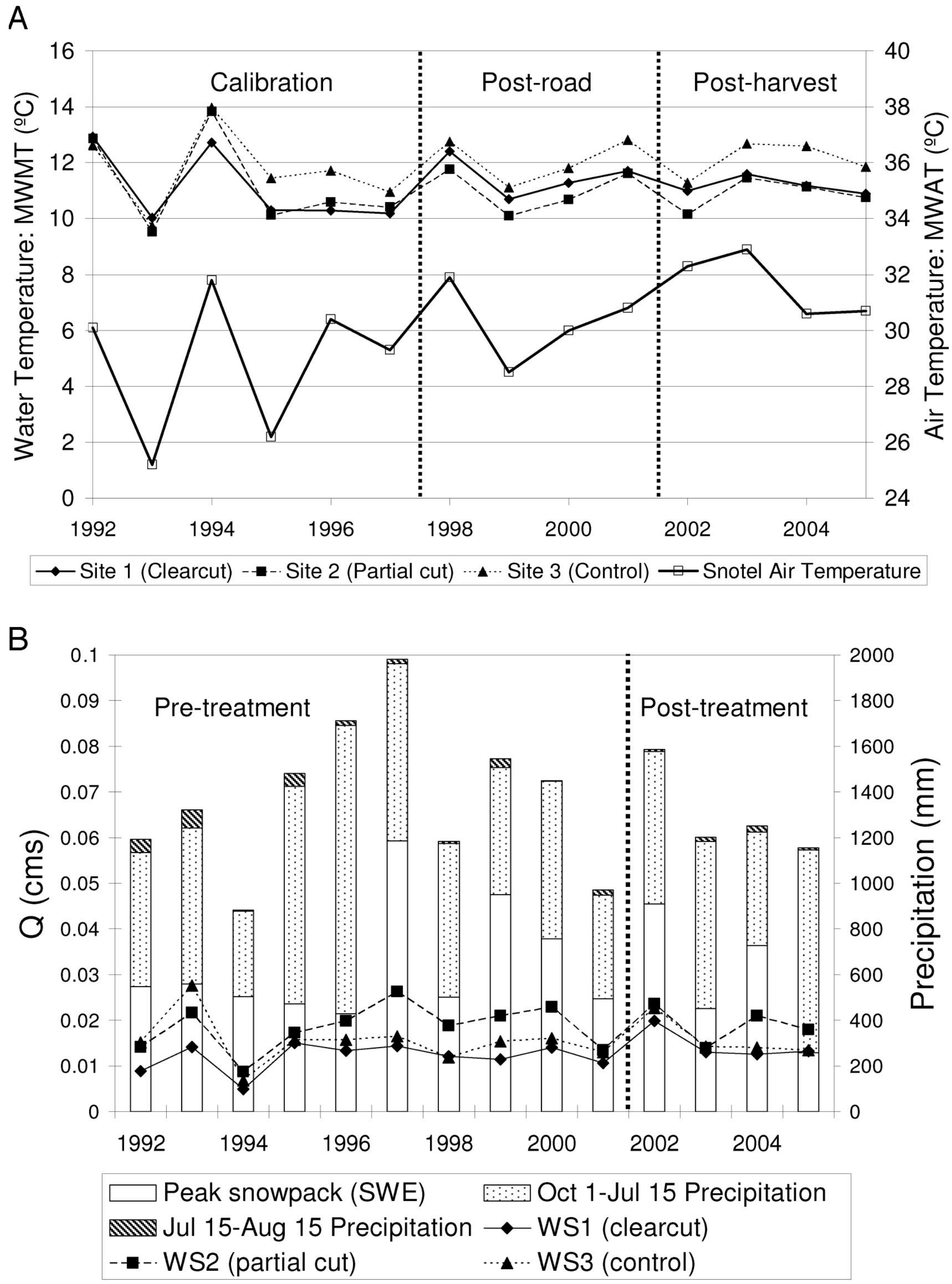
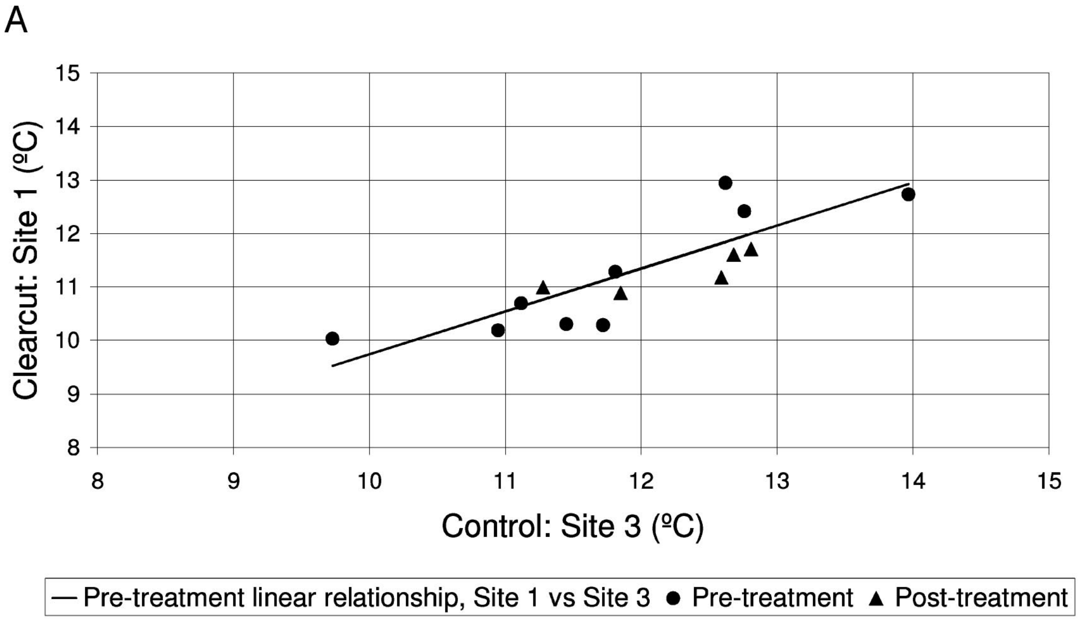


Figure 6. Comparison of (A) maximum weekly maximum temperature (MWMT) and average mid-summer (July 15-August 15) streamflow by treatment period (pretreatment includes calibration and postroad) with (B) maximum weekly maximum air temperature (MWMAT) and snowpack/precipitations patterns from Mica Creek SNOTEL site, 1992–2005.

temperatures of the direct impact partial cut sites and their least-squares linear regression fits (see Figure 10) compare pretreatment relationships between site 8 (partial cut treatment) and 11 (control) and between 10 (partial cut treatment) and 9 (control). Regression fits had r^2 values of 0.96 (8 versus 11) and 0.98 (10 versus 9). Pretreatment linear regression intercepts and coefficients were calculated for each treatment/control pair (see Table 1), and were used to predict maximum daily water temperatures for the posttreatment time period.

Clearcut Treatment Sites (1e, 4, and 6)

A significant change between the actual and predicted values for posttreatment data, at site 1e ($P < 0.01$) and site 4 ($P < 0.01$) was indicated by a Student's t-test (Table 2).



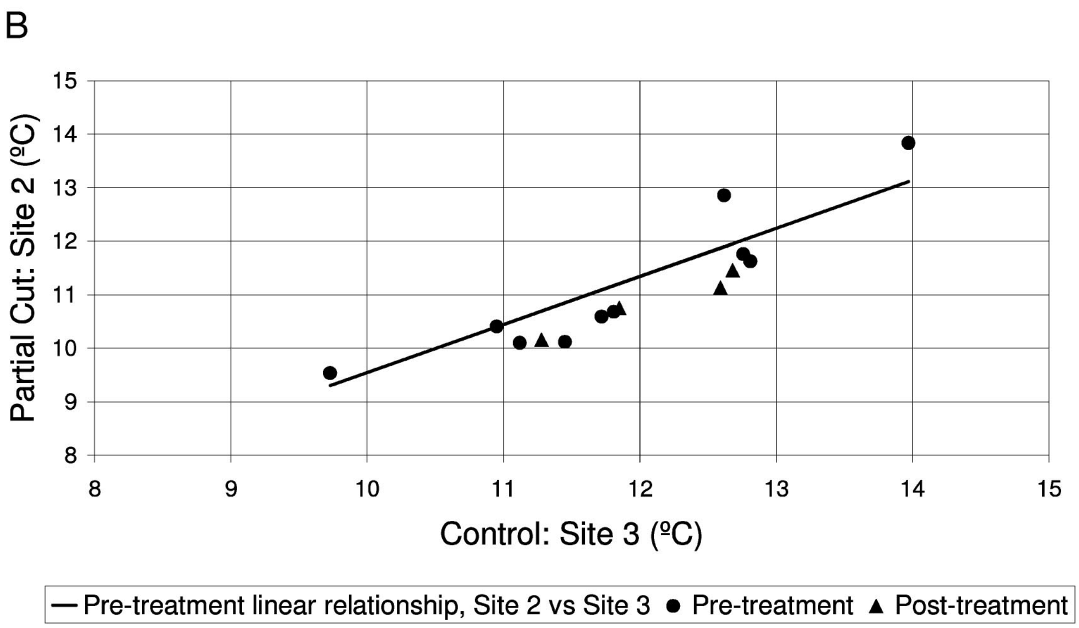


Figure 7. Maximum weekly maximum temperature (MWMT). (A) Clearcut treatment (1 versus 3) and (B) partial cut treatment (2 versus 3), 1992–2005.

Table 4. Summary of peak annual stream temperature and timing, long-term sites, 1992–2005

	Site 1 (clearcut)		Site 2 (partial cut)		Site 3 (control)	
Year	Maxima (°C)	Date	Maxima (°C)	Date	Maxima (°C)	Date
1992	13.5	14 Aug	13.4	14 Aug	12.9	18 Aug
1993	10.2	6 Aug	9.7	6 Aug	10.2	20 Aug
1994	13.2	3 Aug	14.2	25 Jul	14.4	25 Jul
1995	10.9	9 Jul	10.6	9 Jul	12	20 Jul
1996	11	28 Jul	11.3	28 Jul	12.5	25 Jul
1997	10.7	6 Aug	11	6 Aug	11.5	6 Aug
1998	13	27 Jul	12.4	5 Aug	13.4	5 Aug
1999	11	2 Aug	10.5	29 Aug	11.6	29 Aug
2000	11.6	31 Jul	11	31 Jul	12.3	31 Jul
2001	12	17 Aug	12	17 Aug	13.2	17 Aug
2002	11.5	13 Jul	10.5	13 Jul	11.9	13 Jul
2003	11.8	23 Jul, 30 Jul	11.8	30 Jul	12.9	30 Jul
2004	11.5	17 Aug	11.5	17 Aug	12.9	16 Aug, 17 Aug
2005	11.1	31 Jul	10.9	31 Jul	12.1	31 Jul

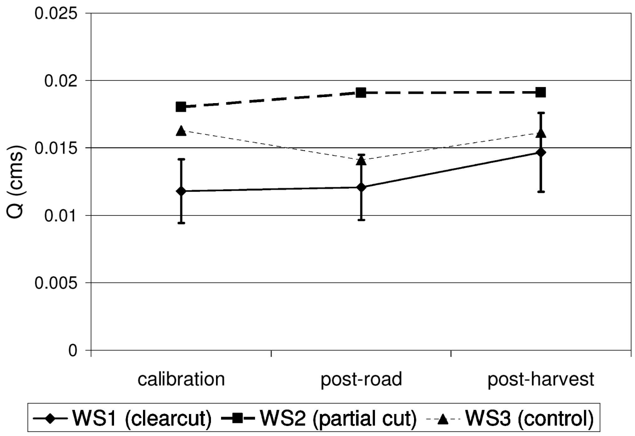


Figure 8. Average streamflow at long-term sites by treatment period (pretreatment includes calibration and postroad) during mid-summer (July 15-August 15), with site 1 (clearcut) 20% streamflow measurement error bands.

A marginally significant change was detected at site 6 (P = 0.06). Mean change resulted in an estimated temperature change of +0.4°C at site 1e, +1.9°C at site 4, and −0.1°C at site 6, respectively. An increase in water temperature that declines over subsequent years is evident based on predicted and actual peak water temperatures (Table 3). At the class I/class II interface zone downstream of the clearcuts (site 1e), results show estimated heating effects of 0.5°C in 2002 and 0.4°C in 2003, but negligible effect (−0.1°C) in 2004 and 2005. The temporal reduction in apparent posttreatment effects is also evident at site 4, where results show estimated heating effects of 3.6°C in 2002 and 2.9°C in 2003, but reduced heating effects of 1.3°C in 2004 and 1.4°C in 2005. It is not evident from the data whether these changes were due to vegetation regrowth or interannual climatic variability. There is no discernible increase in maximum temperature from the clearcut harvesting in the reach containing site 6, and no observable trend with posttreatment data and regression linear fits (see Figure 9), which may be due to large groundwater or hyporheic flow in this reach. Further investigation of this intermittent reach is discussed in the longitudinal temperature trends section.

Partial Cut Treatment Sites (8 and 10)

A Student's t-test (see Table 2) between the actual and predicted data values for posttreatment data at site 8 (P = 0.08) and site 10 ($P < 0.01$) showed mixed results. Site 8 exhibited a negligible change (−0.1°C), while site 10

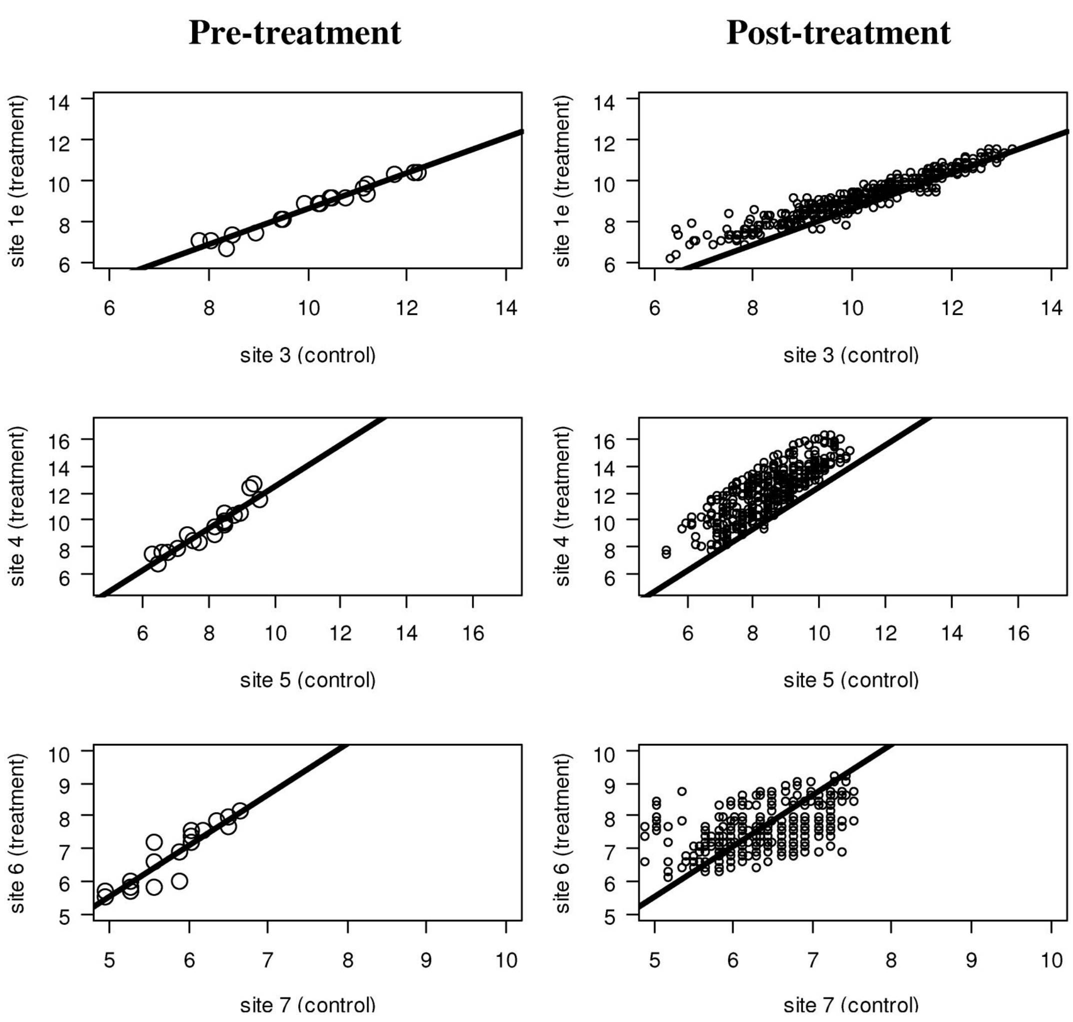


Figure 9. Pretreatment and posttreatment linear regression relationships of maximum daily water temperatures (°C) at direct impact clearcut sites. Pretreatment regression lines have been added to all plots.

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showed an estimated heating effect of 0.4°C. Site 8 showed an estimated heating effect of 0.6°C in 2002, and very slight (i.e., <0.3°C) changes from 2003 to 2005, based on measured and predicted annual peak water temperatures (Table 3). Posttreatment effects at site 10, although statistically significant in the *t*-test, exhibited minimal changes in peak stream temperatures (0.0 to 0.3°C) in the individual years after harvest. Although there may appear to be a slight heating effect when observing relationships between posttreatment data and regression analysis linear fits (see Figure 10), there is minimal to no change in annual peak stream temperature.

Harvest Effects on Canopy Cover

The importance of riparian shade (Beschta 1997, Johnson 2004) and the role of buffer strips (Newton and Cole 2005) are well documented. A mean value for canopy cover at the 10 transects at each of the eight class II reaches were calculated, and reaches were summarized annually by treatment type. Preharvest canopy measurements ranged from 56% to 88%, with an average of 70% in the control reaches, 63% in the clearcut reaches, and 74% in the partial cut reaches (Figure 11). These are typical values for Mica Creek, where riparian canopy cover upstream of the long-term monitoring sites averages from 70% to 80%. In the posttreatment period from 2002 to 2005, the control reach average remained near 70%. In the clearcut reaches, canopy was reduced to 52% in 2002 and 41% in 2003, immediately following broadcast burning and replanting. Research in British Columbia similarly found 40% to 60% of pretreatment shade retained after a harvest treatment that reduced canopy cover by 50% (Mellina et al. 2002). There is also evidence that seasonal canopy, in the form of deciduous shrubs, forbs, and grasses, is increasing overall cover in clearcut reaches toward preharvest levels over the 4 years since harvest. In 2004 and 2005, overall canopy was measured at 56% and 54%. Streamside shade recovery can be attributed entirely to low-lying understory species, as evidenced by the increase in understory/deciduous cover of 26% in 2003 to 39%

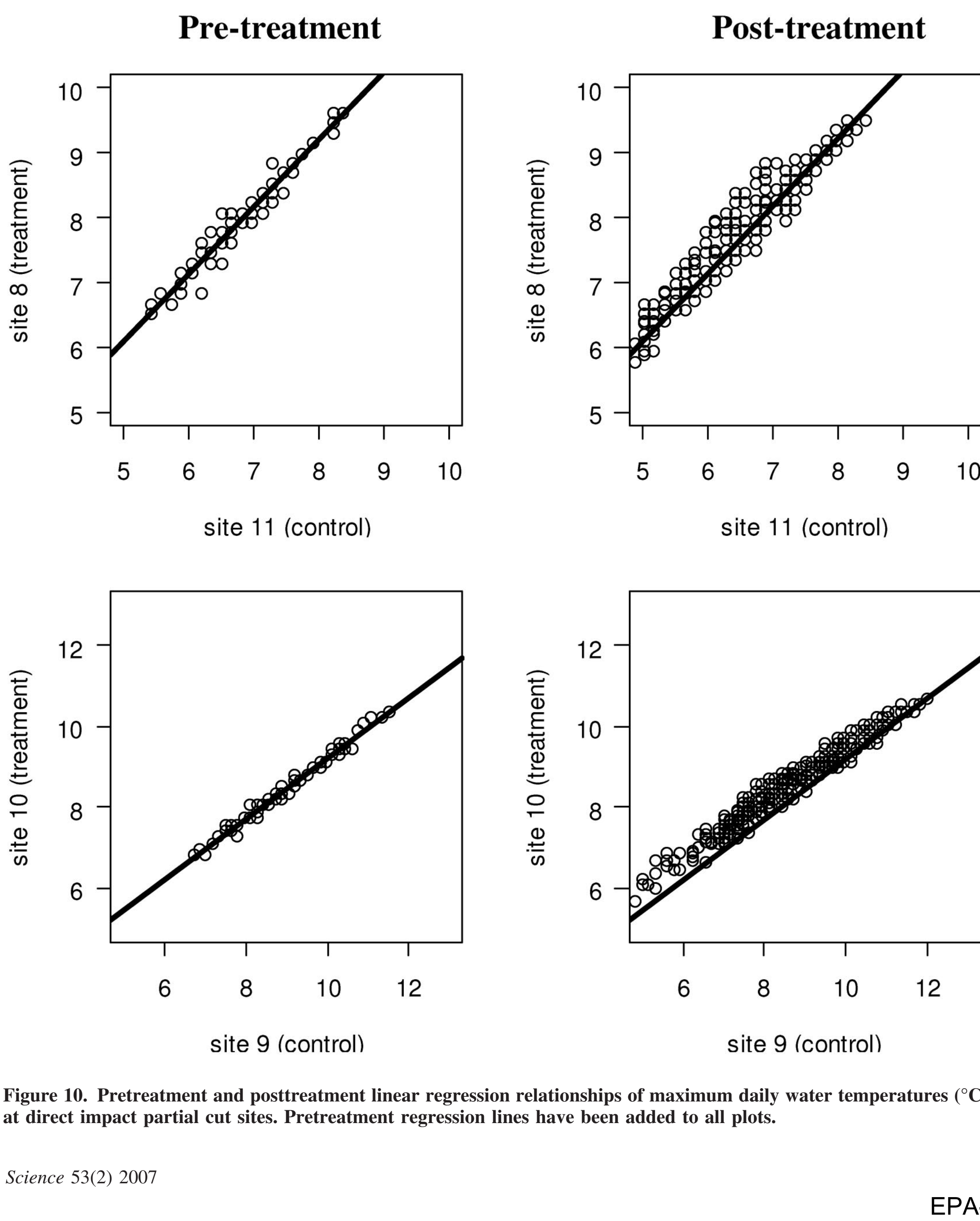

Figure 10. Pretreatment and posttreatment linear regression relationships of maximum daily water temperatures (°C) at direct impact partial cut sites. Pretreatment regression lines have been added to all plots.

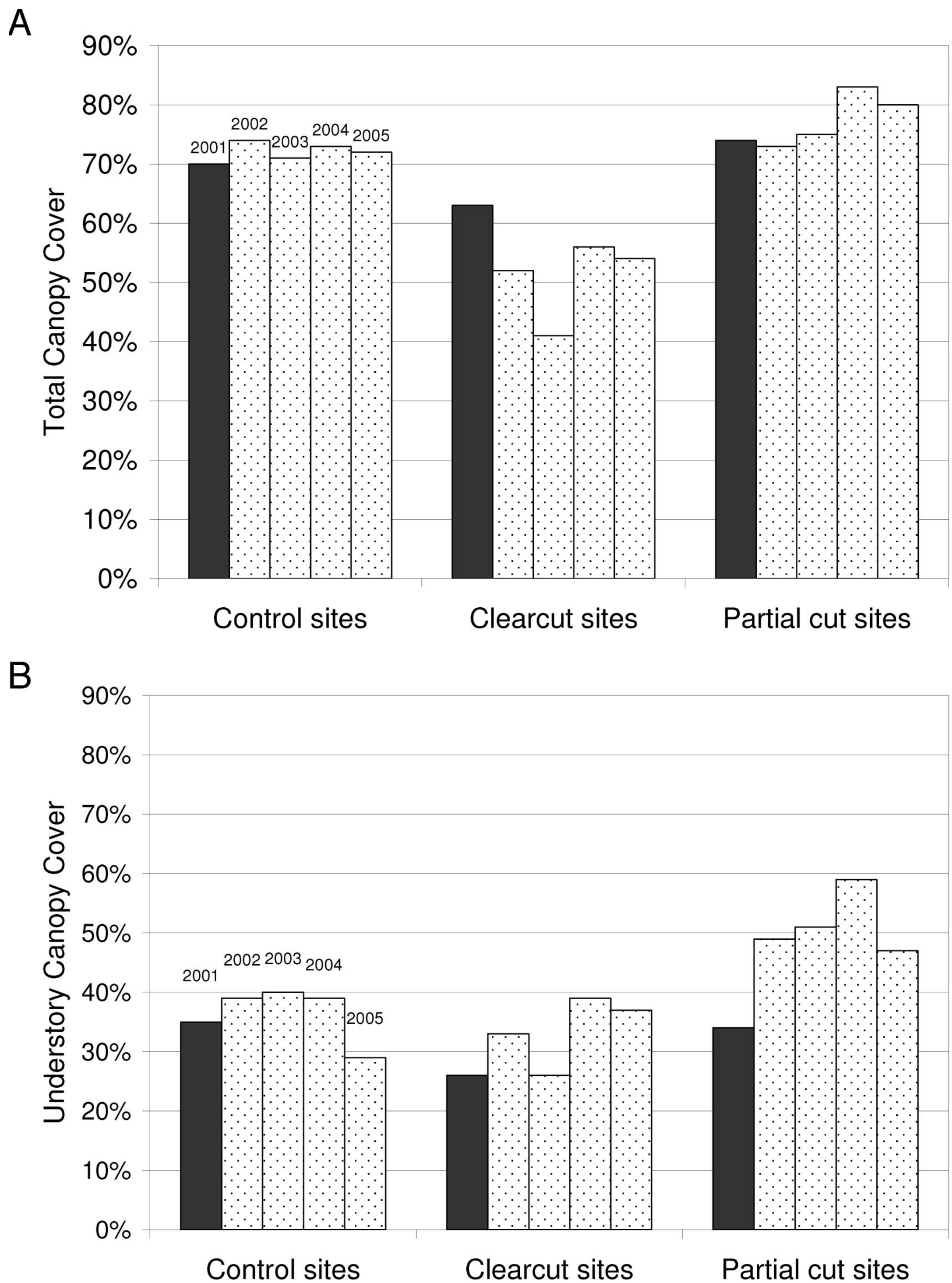

Figure 11. Summary of class II. (A) Total canopy cover measurements and (B) understory canopy cover measurements taken at water surface, pretreatment (2001) and posttreatment (2002–2005).

and 37% in 2004 and 2005, respectively. In the partial cut reaches, canopy shade remained near 75% in both pretreatment and posttreatment time periods.

Based on understory/deciduous stream canopy observations, there is a potential 10% to 15% underestimation of midsummer canopy cover at treated reaches for 2001, because harvest activity required that these data be collected several weeks earlier than subsequent years. This may explain, at least to a degree, the relatively small postharvest reduction in surface canopy cover in the clearcut reaches, as roughly 10% to 15% of the understory/deciduous pretreated canopy may have been missed due to measurement timing in 2001. Understory vegetation appears to have increased posttreatment, which is expected, as the removal of the forest overstory canopy allows more incoming solar energy to reach the forest floor. Radiative transfer processes that provide energy to streams should also aid understory vegetative growth by way of increased photosynthetic activity,

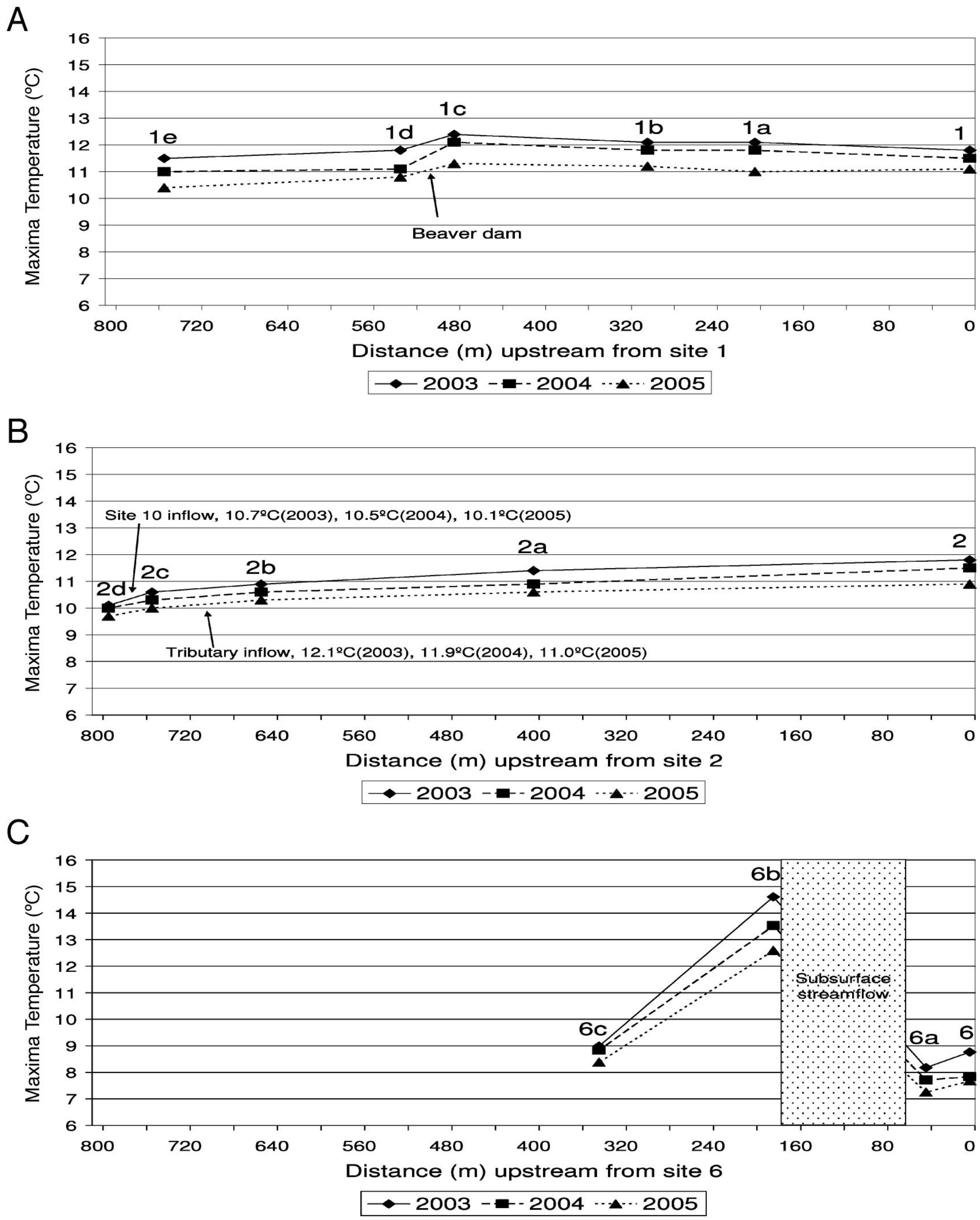

Figure 12. Longitudinal peak water temperatures (A) within WS1 class I SPZ (1–1e), (B) within WS2 class I SPZ (2–2d), and (C) within clearcut treatment intermittent reach (6–6c).

and may be an important process contributing to the thermal recovery of disturbed stream systems. There is a possibility that net radiation beneath areas shaded by understory cover is different from areas shaded by overstory vegetation due to differences in the structure and radiative properties of overstory and understory canopies (Moore et al. 2005). Further research is warranted to quantify cover differences on both the solar and thermal radiative energy balance, and to assess the combined role of slope, aspect, and vegetative cover.

Longitudinal Temperature Trends

In WS1 there was abrupt warming between sites 1d and 1c, but then maximum values decline downstream toward site 1, the long-term monitoring site (Figure 12). Peak water temperatures show increases of 0.6°C (2003), 1.0°C (2004), and 0.5°C (2005) between sites 1d and 1c, which are no more than 50 m apart, and increases are apparently due to a nonactive, but still functional, beaver dam. Canopy cover is reduced to approximately 20%, and the stream water surface experiences increased incoming shortwave radiation, both by a reduction in riparian shade and a widened stream channel. Significant heating within a large beaver pond complex has been previously documented (Robison et al. 1999). This is an example of how other factors, including beaver populations, wide channels of larger streams, and topographic features can produce variations in otherwise smooth spatial temperature trends. These factors should be taken into consideration when estimating accurate background canopy cover and modeling water temperature in headwater streams. In WS2, peak water temperatures appeared to be affected by tributary inflows within the class I SPZ. Peak stream temperatures continued to increase downstream toward site 2. There appears to be a heating effect caused by warmer tributary inflows between sites 2d and 2c as well as between 2c and 2b.

Longitudinal trends were also examined in the intermittent reach upstream of the clearcut treatment site 6. Due to complexities in the energy balance of headwater streams, downstream heat dissipation can occur within a short distance (Caldwell et al. 1991, Sugden et al. 1998, Zwieniecki and Newton 1999). Results from sites 6 and 6a–c support this, as there appears to be relatively large groundwater/hyporheic exchange within this reach. The farthest upstream site (6c) exhibited peak stream temperatures ranging from 9.0°C to 8.4°C from 2003 to 2005. After flowing 160 m through the clearcut reach to site 6b, peak water temperatures ranged from 14.6°C to 12.6°C from 2003 to 2005. Compared to peak values from the upstream site 6c, these increases ranged from 5.6°C to 4.2°C over the 3 years. The stream then goes subsurface, and temperatures were much cooler at the re-emergence point ~125 m downstream (6a). Annual peak stream temperatures at site 6a ranged from 8.2°C to 7.2°C from 2003 to 2005. Although only ~40 m apart, some stream heating was evident between sites 6 and 6a. At site 6, the annual peak stream temperatures from 2003 to 2005 ranged from 8.8°C to 7.7°C.

Whether or not the declining temporal trend between sites 6c and 6b can be attributed to increasing understory cover or interannual hydroclimatic variability, this trend is worthy to note, and further monitoring during hydrologic recovery will help answer this. It is also important to note that the stream was dewatering as it moved from 6c to 6b, so by 6b there was only a trickle of surface flow. Nonetheless, it is interesting to note that the surface water warmed markedly from site 6c to 6b, went entirely subsurface, and re-emerged much cooler at site 6a. Previous research has examples of pronounced stream cooling similar to this, where gross cooling effects on daily maximum temperature reached estimates of ~3°C, with a combination of cooling from groundwater inflow and hyporheic exchange (Story et al. 2003). This example helps to emphasize some of the complex stream temperature dynamics that can occur in first-order headwater streams.

Conclusions

Although clearcutting increased maximum daily temperatures in Mica Creek directly downstream of harvest in one clearcut reach, it appeared to have a slight impact on temperatures in the downstream fish-bearing reaches. At long-term monitoring sites on fish-bearing streams with a substantial amount of pretreatment data, there appears to be no change to the extent or timing of summer maximum water temperature in watersheds as a result of either 50% clearcut or 50% partial cut timber harvest. Regression analysis indicates that there was a slight cooling in posttreatment peak temperatures, which may be due to increased midsummer streamflows resulting from timber harvest, as observed by Hubbart et al. (2007). Based on these results, it appears that the BMP applied in this study effectively negated the effect of timber harvest on stream temperatures in reaches below areas of direct impact. Subsequent monitoring at the established sites will also provide a better understanding of the effectiveness of current BMP on maximum water temperature response during canopy recovery in sites of direct impact. This research is consistent with other studies that have recognized the complexities of monitoring water temperature in headwater streams. Although direct incoming shortwave solar radiation appears to be the dominant energy input for increasing stream water temperature, it is vital to consider other conductive and convective energy transfers such as substrate heat exchange, ambient air temperature, groundwater inflows, hyporheic exchange, and harvest impacts on streamflow regime (i.e., changes in amount or timing of water yield) when considering both direct and cumulative watershed impacts.

Canopy cover in clearcut reaches was reduced less than expected when measured at the water surface due to low-lying herbaceous vegetation. In many headwater riparian areas where harvesting occurs, the importance of understory vegetation can often be overlooked. In both clearcut and partial cut treatment reaches, there are indications that understory vegetation increased posttreatment, probably due to increased solar radiation reaching the riparian forest floor. In addition, contemporary practices may leave some overstory canopy, whether as nonmerchantable trees or wildlife reserve trees. This green tree retention in clearcuts provides some relief from total overstory removal, and is now part of sustainable forestry initiatives and comprehensive watershed landscape planning that many private timber companies now have in place. Failure to regard these factors could result in errors when estimating postharvest riparian shade and for the prediction of peak stream temperatures.

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Memorandum

May 30, 2014

To: Alan Henning, USEPA

From: Peter Leinenbach, USEPA

Subject: Review of the headwater study (Gravelle and Link (2007)) referenced in OFIC's CZARA comment letter, which they conclude that "temperature impacts are not transported downstream" from riparian harvest.

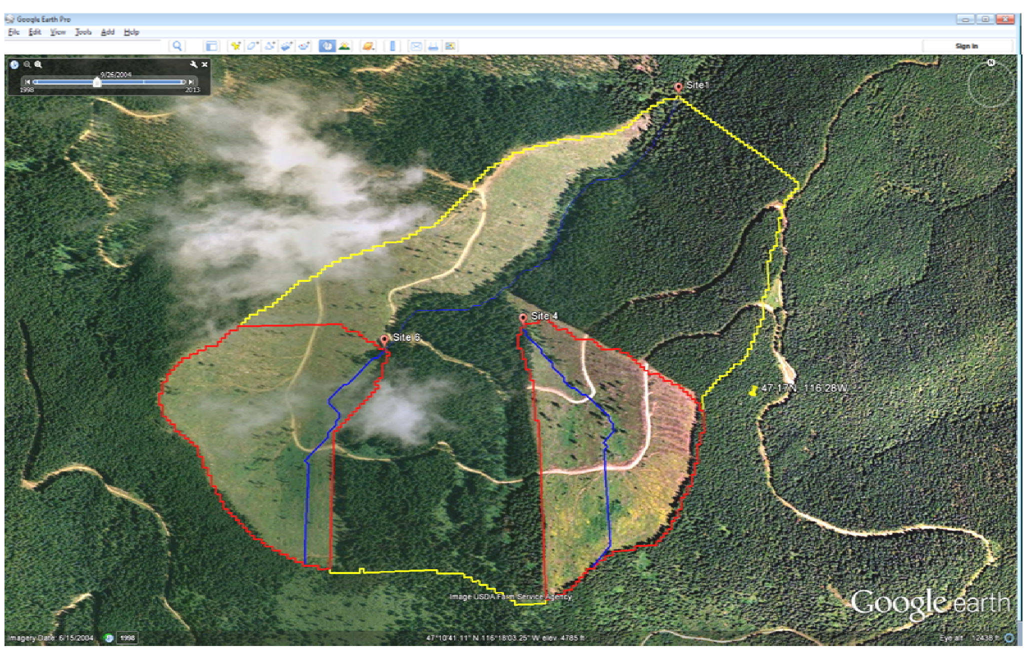
Summary – There is no evidence presented in this document which indicates that the energy load resulting from the clearcut harvest is lost to the system. It appears that the heat load is simply diluted with cold groundwater/hyporheic flows in the downstream reach (i.e., flows increase almost 5 fold from the clearcut harvest area to the downstream sampling reach). The energy added to the system is still present in the water and it is being transported downstream. Finally, this is only one stream with very unique characteristics – it is problematic to assume that all streams will have similar characteristics.

Discussion - The clearcut reaches associated with the Gravelle and Link (2007) study in Mica Creek basin are very limited and have very low flow conditions (**Table 1** and **Figure 1**).

Table 1. Calculated median August stream flows for the clearcut sites (Calculated with StreamStats)

Site Number	AugustD50 Flow (cfs)
1 (Downstream Reach)	0.62
4	0.12
6 (Intermittent Stream Reach)	0.13

Figure 1. Clearcut Harvest Sites in the Mica River Study
[Clearcut sites are 4 and 6 and the downstream site is 1]



Clearcut Site 6

Note that the estimated August median flow for site 6 is only 0.13 cfs (estimated using SteamStats – **see Table 1**), and that the downstream flow was 0.62 cfs. This indicates that, although this stream has very low flow conditions, it is a gaining flow reach. The authors reported that these river reaches have "large groundwater or hyporheic flow" which would result in "no discernible increase in maximum temperature from the clearcut harvesting in the reach containing site 6" (Page 199). This indicates that the added heat load from the clearcut harvest is likely masked through the dilution with cold groundwater, and thus the added energy is not lost to the system (i.e., the energy is still in the system; it is only masked by the dilution with the groundwater).

The authors also reported that Reach 6 was intermittent in flow. It appears from the data (i.e., Figure 12 in the Gravelle and Link (2007) paper – image attached below) that the effects of clearcut harvest at Site 6B are removed from the stream going subsurface Accordingly, this clearcut segment is not evaluating the effect of clearcut harvest on stream temperature upstream of Site 6 **<u>and therefore should not be included as an evaluation point in this study</u>** (i.e., the river temperature regime essentially starts over when it resurfaces at site 6a). (It is important to note that this figure indicates that stream temperatures are dramatically increasing (+5*C) within the 6c to 6b clearcut reach).

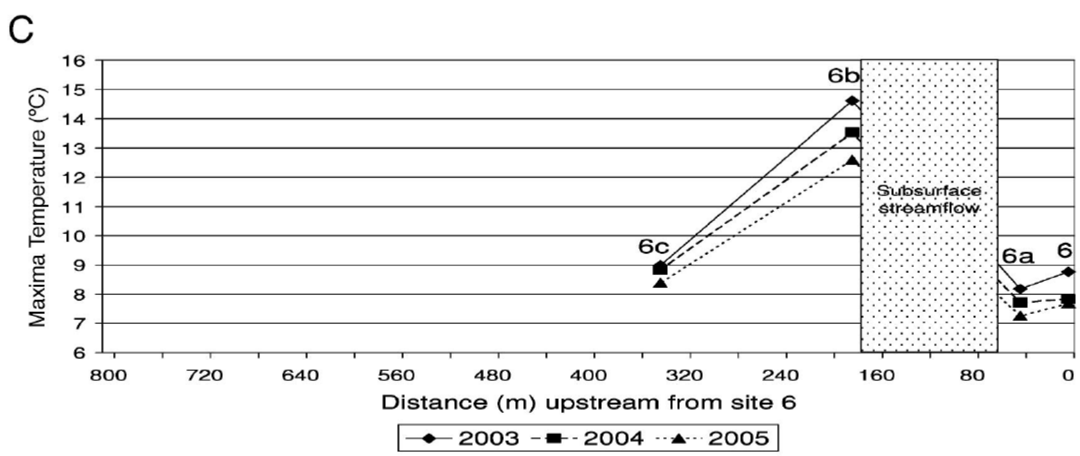


Figure 12. Longitudinal peak water temperatures (A) within WS1 class I SPZ (1–1e), (B) within WS2 class I SPZ (2–2d), and (C) within clearcut treatment intermittent reach (6–6c).

Clearcut Site 4

The only other clearcut segment included in this study was Clearcut Site 4. The authors reported that the temperatures increased 3.6*C from clearcut harvesting in this reach and the authors also noted that "there was no significant increase in water temperature maxima at the downstream fish-bearing sites" (i.e., Site 1) (Abstract).

Downstream of Clearcut Zones

The authors concluded that "it appears that the BMP applied in this study [downstream of the clearcut reach] effectively negated the effect of timber harvest on stream temperature in reaches below areas of direct impact" (page 203). The BMPs which the authors are referring to are riparian FPA buffers with clearcut harvest occurring outside of these buffers for the north stream bank along this SW/NE flowing stream (see Figure 1 above).

First, it is quite possible that the effectiveness of these BMPs to reduce stream temperature may have been much less if the harvest had occurred on the southern river bank of the river.

Second, it is much more likely that cold groundwater/hyporheic flow inputs within this reach is the cause for the authors to not observe an increasing temperature trend at the downstream Site 1 location, than these buffers.

Third, it is problematic to assume that IFPA buffers will mitigate upstream heat loads. In fact, IFPA buffers along fish bearing streams have been consistently shown to result in increase stream solar loading (i.e., by rule they can current result in a 25% reduction in stream shade) which is a net energy load to the stream which should not act as a method to dissipate heat (e.g., These buffers are not BMPs for upstream heat loads).

Finally, it appears that heat loads associated with Clearcut harvest within Reach 4 are diluted 4.8 times by the time it reaches Site 1 (i.e., 0.62 cfs/0.13 cfs = 4.8). In other words, the flow increases almost 5 fold from Site 4 to Site 1. It appears that the ground water temperature is around 8*C (see the temperature for Site 6a in the image attached on the proceeding page), so this increased flow from the cold groundwater/hyporheic would be more than enough to "mask" the effects of the 3.6*C temperature increase at Site 4. However, the energy load to the system is still present in the water.